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EDWARD J. FAEDER, Ph.D., R.E.A.
DIRECTOR
ENVIRONMENTAL PROTECTION & SAFETY

October 9, 1989

EJF1089/584

Ms. Alisa Greene
Remedial Project Manager
Superfund Program
U.S. EPA (T-41)
Region IX
215 Fremont Street
San Francisco, CA 94105

Dear Ms. Greene:

I am providing you with the information Lockheed has collected regarding the treatment of nitrate in groundwater in response to your request. These data was collected as a result of Lockheed's concern over nitrate levels in the local groundwater. Our focus has been to develop a better understanding of the technology in general, its associated costs, and the relevant waste disposal requirements (e.g., brine disposal).

Included are two papers providing data on system performance, capital and O&M costs, waste generation for a treatment facility located in McFarland California. This facility was designed and constructed by Boyle Engineering Corporation in conjunction with the EPA. Some unit costs for the Glenwood treatment facility are enclosed. This facility, which serves the Cresenta Valley County Water District, was also built by Boyle Engineering.

If you have any questions regarding this information, please feel free to call Mr. David Jensen at (818) 847-5144. Alternatively, you may wish to contact Boyle Engineering directly at (714) 476-3300.

Sincerely,

Edward J. Faeder

Edward J. Faeder

MAILING LIST

W/O Enclosures:

Mr. Melvin L. Blevins, Watermaster, Upper Los Angeles River Area
Mr. Dennis Dickerson, California Department of Health Services, Toxic Substances Control Division
Mr. Mike Hopkins, Glendale Public Service Department
Mr. Bruce Kuebler, Los Angeles Department of Water and Power, Water Quality Division
Mr. Gilbert Torres, State Water Resource Control Board
Mr. Fred Lantz, Water Operations Manager, Burbank Public Service Department
Mr. Henry R. Venegas, Room 1336, Los Angeles Department of Water and Power
Mr. Ernest F. Wong, Room 1304, Los Angeles Department of Water and Power
Mr. Hank Yacoub, Supervising Engineer, California Regional Water Quality Control Board
Mr. Walter W. Hoye, Los Angeles Department of Water and Power
Mr. Michael Mohajer, Los Angeles County Department of Public Works, Waste Management Division
Office of the Mayor, City of Burbank
Office of the Mayor, City of Glendale
Office of the Mayor, City of Los Angeles
Mr. Robert R. Ovrum, Burbank City Manager
Ms. Julie Scott, Acting Burbank City Attorney
Mr. Steven Tekosky, City of Los Angeles, Office of City Attorney
Ms. Bonnie J. Wolstoncroft, State Water Resources Control Board, Office of Chief Counsel

Boyle Engineering Corporation

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Telex 685561

September 12, 1989

Jim Hamilton
Lockheed Aeronautical Systems Company
PO Box 551
Burbank, CA 91520-3830

<u>Technical Paper Request</u>

Mr. Hamilton, here's a copy of the technical papers you requested:

> *Nitrate Removal from Contaminated Water Supplies*
> *Volumes I and II*

If you would like more information on these subjects, please contact Boyle Engineering's Orange County office. Thanks for your interest.

BOYLE ENGINEERING CORPORATION

Mary C. Fernandes

Mary C. Fernandes
Editor, Corporate Marketing

Enclosure

cc: Vic Opincar

CR-B99-197-00/mcf

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LOCKHEED AERONAUTICAL SYSTEMS COMPANY
Attention Mr. Jim Hamilton, ETS Specialist
P.O. Box 551
Burbank, CA 91520-3830

September 22, 1989

ASCE-CVCWD Field Trip,
Glenwood Nitrate Removal Plant

Jim, it was great seeing you Tuesday and meeting Dave Jensen. We trust you found the tour interesting and informative.

I am enclosing some additional information that Dave requested on the projected unit costs on the Glenwood Plant. Please keep in mind that each plant will be different, requiring site specific engineering and having varied cost components, particularly on the brine disposal requirements.

We would be most delighted to meet with you to discuss further your nitrate removal objectives. Please give me a call whenever you are ready for us to schedule a presentation.

BOYLE ENGINEERING CORPORATION

Ron

Ronald N. Thompson, P.E.
Senior Civil Engineer

Enclosure

ss

OC-B99-197-00

GLENWOOD NITRATE GROUNDWATER RECLAMATION PROJECT

UNIT COSTS ($ PER ACRE FOOT)

	Unit Cost Basis		
	New Yield	Base Load	Base Load W/ Blending
Basic Plant			
Capital	$68	$38	$29
O&M	35	35	27
Total	103	73	56
Brine Disposal			
Capital	66	37	28
O&M	4	8	6
Total	70	45	34
Total Project			
Capital	134	75	57
O&M	39	43	33
Total	173	118	90

CRESCENTA VALLEY COUNTY WATER DISTRICT

BOYLE ENGINEERING CORPORATION - AUGUST 18, 1989

Some or all of the raw water may be passed through the ion exchange vessels. Deciding whether to treat all of the water, or only some of it, is generally based on cost considerations. If only some of the water is treated, the treated portion is mixed with the untreated water to produce a blended water with a nitrate concentration less than the MCL.

WASTEWATER QUALITY AND QUANTITY

As with all treatment processes, some wastewater is produced. Typically, about two percent of the water delivered is used for regeneration and discharged to waste. For example, a one MGD plant will produce about 20,000 gallons per day (GPD) of wastewater.

The TDS of the wastewater is generally about 5,000 mg/L. The ions in the wastewater consist mostly of sodium, nitrate, sulfate, and chloride.

The wastewaters from the four plants described above are, or will be, discharged into the community sewer systems.

SITE REQUIREMENTS

The ion exchange nitrate removal process equipment requires a remarkably small area. A 1 MGD plant covers an area about 30 feet square. A 3 MGD plant needs an area of about 40 feet by 50 feet.

The process equipment is very quiet. In fact, when one water district manager turned on his plant for the first time, he had to look at a flow meter to be sure it was on!

COSTS

Assuming no unusual site or wastewater disposal circumstances, the capital cost for a plant to treat water that, except for the nitrate concentration, is acceptable for drinking, is in the range of $0.30 to $0.60 per gallon per day (GPD) of capacity. This cost range applies to plants of one MGD and greater capacity. Generally, the larger the plant, the lower the cost.

Operation and maintenance (O&M) costs are usually in the range of $30-$50 per acre-foot (AF) ($90-$150 per MG). The plants can be automated so as not to require continuous operator attention.

DETAILED PROCESS DESCRIPTION

Usually, it is necessary to design a nitrate removal plant for continuous operation. That is, the plant must continue to treat water while a vessel is being regenerated. A three vessel arrangement is most cost effective.

The basic scheme is to have two vessels in service (treating water) while the third vessel is being regenerated (brined, rinsed, and backwashed). The vessels are "rotated" through the steps with the "lead vessel" being half way through its "service cycle" before the "lag vessel" is brought into service. The third vessel is being regenerated, or in "standby", if regeneration has been completed, while the "lead" and "lag" vessels are treating water. When the "lead" vessel is exhausted (needs regenerating), it is taken out of service, the "lag" vessel becomes the "lead" vessel, and the "standby" vessel becomes the "lag" vessel and the treatment process continues.

United States
Environmental Protection
Agency

Water Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-86/115 Apr. 1987

EPA

Project Summary

Nitrate Removal from Contaminated Water Supplies: Volume I. Design and Initial Performance of a Nitrate Removal Plant

Gerald A. Guter

This report reviews the design, construction, and operation of a 1-mgd nitrate removal plant in McFarland, California. The plant treats groundwater pumped from one of the wells supplying water for domestic use. Nitrates are reduced from approximately 15.8 mg/L NO_3-N to well below the maximum contaminant level (MCL) of mg/L NO_3-N. Included in the design considerations are such factors as water supply, health and safety, level of technology, location, capacity, regeneration frequency, water quality, operational sequence, brine disposal, automatic operation, and performance monitoring. The procedures for both manual and automatic operation are discussed.

Continuous daily (24-hr) operation of the plant was made possible by automatic operation. The presence of the operator is required for approximately 1 hr per day to check performance. Automatic nitrate monitoring of product water was performed once an hour through the use of modified ion chromatography. Daily records of flows, water quality, electrical consumption, salt usage, and manhours were kept to determine operating costs. The total wastewater produced by the nitrate plant was 3.39% of the amount of water delivered to the distribution system from the well. The treated water was 75% of water delivered. Saturated brine was 0.09%, dilute brine was 0.49%, rinse water was 1.76%, and backwash water was 1.14%. All percentages were of the blended water delivered to the distribution system. All waste from the plant was discharged to the McFarland municipal wastewater treatment system, with ultimate discharge to 128 acres of cotton and alfalfa crops.

The amount of water treated by each ion exchange vessel before regeneration was 165,000 gal (260 bed volumes (BV)). The amount of salt used per regeneration was 6.35 lb/ft³ of resin.

Capital costs totaled $311,118 for a 3-ft bed system, and $355,638 for a 5-ft bed system. Operation and maintenance costs were $0.13 per thousand gal when the system was operating at 1 mgd. Total costs, including operations and maintenance (O&M) and amortized capital, were $0.25 per 1000 gal when operating at design capacity of 1 mgd.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This report reviews the operation of a 1-mgd nitrate removal plant at McFarland, California. The plant and supporting equipment are described, and an analysis of the capital cost of construction and the operation and maintenance (O&M) costs are also presented. The data on which this report is based were obtained during the initial adjustment period of the plant and during the first 6 months of automatic operation ending November 30, 1984.

The plant uses the ion exchange process with commercially available resin. The process design is based on the research and pilot studies performed under a previous cooperative agreement with the U.S. Environmental Protection Agency (EPA). The design and operation of the plant were supported by the McFarland Mutual Water Co. (McFMWCo) and EPA under cooperative agreement Nos. CR808902-010 and CR808902-020. Construction of the plant was made possible with funds from McFarland Mutual Water Company, The Kern Co. Community Development Agency, and the Kern County Water Agency. The Community Development Agency is funded by the U.S. Department of Housing and Urban Development (HUD).

This report is the first of a two-volume final report under the existing grant and is restricted to the general subject of the initial operation of the plant. The second volume will include a report on the continuing operation of the plant for several additional months.

Plant Design

A flow diagram is shown in Figure 1. Feed water is supplied directly from the well pump into two of the vessels in the service cycle. Vessel 1 is 50% exhausted when Vessel 2 starts its service period. When Vessels 1 and 2 are in service, No. 3 is in regeneration or standby. After No. 1 is exhausted, 2 and 3 are in service, etc. Service is stopped in any one vessel by an electrical signal from a flow totalizer or by a manual signal.

Electrical conductivity is monitored at well supply and product water locations to detect any brine leakage into the product water. Alarm and shut down occur if product conductivity rises above that of supply water. Nitrate levels are also monitored in the blended product water and excess nitrate can also cause automatic alarm and shut down.

Major consideration was given to the following elements of plant design:

- Water Supply
- Health and Safety
- Level of Technology
- Location
- Capacity
- Regeneration Frequency
- Water Quality
- Operational Sequence
- Brine Disposal
- Automatic Operation
- Monitoring of Performance

Water Supply

The McFMWCo supplies water from its well and through its distribution system for municipal use. The only water source at present is underlying groundwater. Six wells are located in McFarland. Well No. 3 has been discontinued for public use because of too high nitrate levels. Well No. 2 is the location of th nitrate plant now is operation. Recent analysis of Wells 1 and 4 shows nitrate above the maximum contaminant level (MCL).

Table 1 presents data on the water quality of four wells with high nitrate levels. Because of recent projected development trends, two new wells were constructed to serve the developing areas in a remote part of the City and operation will begin shortly.

Health and Safety

Health and safety were the major considerations; and therefore, they took precedence where design conflicts arose. The plant design was reviewed by the California State Division of Health, which issued an operating permit on May 13, 1983. Before issuing the permit, a design review was conducted. The major concerns were that:

1. Brine be isolated from the brine water supply system (this is accomplished with a double check valve).
2. Waste brine and wash water be isolated from the distribution system (this is accomplished by double valves or a block and bleed arrangement).
3. Nitrate levels in supply water be kept below 10 mg/L NO_3-N and preferably below 7 mg/L NO_3-N.
4. A Class 2 State-certified operator be made responsible for plant operation (two employees of McMWCo will quality for this certification).

Level of Technology

The technology used in the mechanical design and planning for the plant relies heavily on that used in the water softening industry. The chemical process design is based on research on the use of anion exchange resins completed under previous EPA grants. Although that research indicated efficiency might be conventional, commercial available strong-base anion exchange resin was used as a basis for design.

Location

Plant location at one of the well sites was dictated by the already-in-place well and distribution system, which have been in use for more than 30 years and are typical for small communities dependent on groundwater. McFarland can draw water from any of the six wells that supply water to an interconnected distribution system. Because the system has no central distribution point, the plant had to be designed to operate from a single well. Well pumps operate on a demand basis; consequently, the plant had to be able to operate in an automatic on-off basis. The design was made to accept water directly from the well pump, treat it for nitrate removal, and allow treated water to flow directly into the distribution system without directing it to a central part of the system and without storage.

Capacity

The delivery capacity of Well No. 2 is approximately 695 gpm (1 mgd on a continuous basis). With nitrate-nitrogen levels in the 16-mg/L range, a 7-mg/L product can be achieved by reducing nitrate to 0 in 70% of the water and blending with untreated water. Studies show a decreased regeneration efficiency as nitrate leakage in treated water approaches zero.

The plant was sized to treat the total well production rate, to provide a blending facility to allow a range of treatment level from partial to complete, and to provide sufficient capacity to meet rising nitrate levels.

Regeneration Frequency

Anion exchange resins require regeneration with a sodium chloride brine. For uninterrupted service, it is necessary to have a standby regenerated bed of resin in a second vessel starting into operation when the first starts its regeneration cycle.

Regeneration times (about 120 min in McFarland) are fixed regardless of bed size, whereas bed exhaustion times or service periods vary with bed size and capacity (see Table 2). Bed exhaustion time should be longer than the regeneration time if two beds are allowed.

Long standby periods require larger beds and added resin inventory and equipment costs. Bed size is also limited in that deeper beds give higher backpressure and large area beds give lower flow rates (hydraulic loading), which promote reverse adsorption or dumping of nitrate from resin to product water.

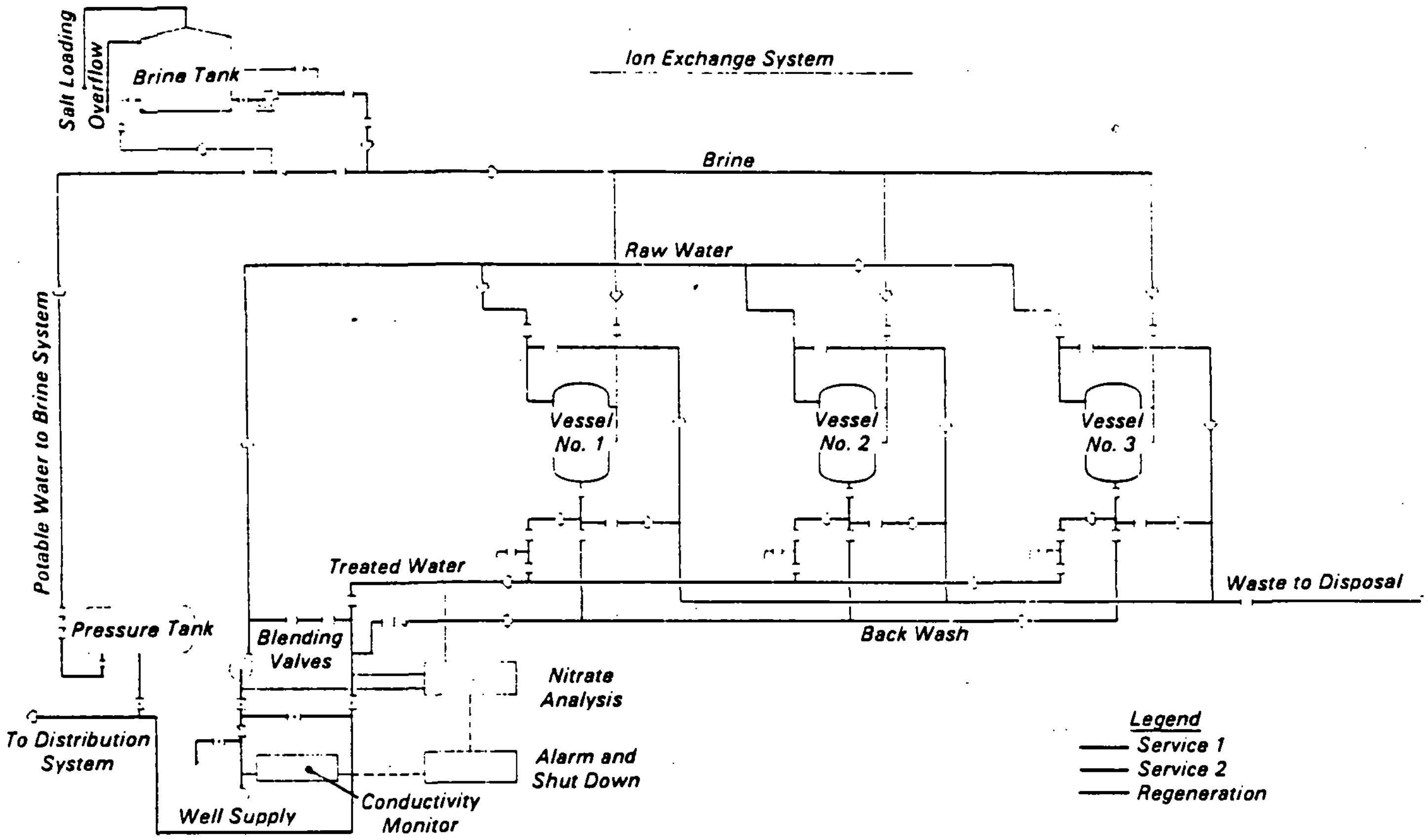

Figure 1. Flow diagram.

Table 1. *Composition of McFarland Well Water (ppm) in 1980*

Item	Well No. 1	2	3	4
Date	5-8-80	4-9-80	5-1-80	4-16-80
Calcium	28	88	156	78
Sodium	50	65	100	72
Bicarbonate	88	102	121	95
Chloride	28	86	94	51
Sulfate	51	105*	310	182
Nitrate-N	6.8	15.2	22.1	10.6
TDS	235	466	827	485
pH	7.7	7.2	7.3	7.7

*Analyses on 5/31/78 showed sulfate levels of 261 ppm and nitrate levels of 78 ppm.

Table 2. *Estimated No. of Regenerations per Vessel per Day*

Bed Volumes Treated	Percent Treated Water in Blend and Bed Depth: 100%		75%		50%		25%	
	3 ft	5 ft	3 ft	5 ft	3 ft	5 ft	3 ft	5 ft
200	2.67	1.60	2.00	1.20	1.34	0.84	0.67	0.40
300	2.00	1.20	1.50	0.90	1.00	0.60	0.50	0.30
400	1.33*	0.80+	1.00	0.6	0.67	0.40	0.33	0.20

* Twelve-hour service period per vessel and 6-hr standby per vessel.
+ Twenty-hour service period per vessel and 10-hr standby per vessel.

Water Quality

Water quality is an extremely important factor in nitrate ion exchange technology. Two areas of concern are:

1. All major anions interfere to reduce bed capacity and change product water quality.
2. Resin ion equilibria and flow rate effects must be taken into consideration to obtain proper bed operation.

Operational Sequence

The operational sequence is selected either through a programmable controller or manual push-button operation on each vessel. Each vessel undergoes the following sequence:

Service, brine injection, brine displacement, slow rinse, bachwash/resin declassification.

Under automatic control, any combination of valve operation can be selected in one or more programs.

Brine Disposal

Brine is disposed to the municipal waste treatment facility. Review by the City of McFarland and the California State Water

Quality Control Board was done through the environmental impact report process. The quality of dissolved solids added to wastewater caused concern for its impact on soil and groundwater in the disposal area. Treated wastewater is discharged to 128 acres of agricultural land used for growing animal feed and cotton.

A monitoring program is in effect in the discharge area to monitor soil, groundwater, and wastewater.

Automatic Operation

Automatic operation of the plant was considered essential to reduce the amount of manpower required to sustain continuous operation. The only manual operations required were turning the system on or off and inspection of data and plant operation.

Monitoring of Performance

Extensive plant monitoring was incorporated into the design because this was a demonstration plant and it was necessary to determine operating costs, performance, and reliability. The methods of flow and batch measurement presented no difficulty; however, the method of continuous nitrate monitoring was in doubt because of the lack of reliable methods. Ion chromatography was chosen as the method for testing, since it appeared adaptable to continuous nitrate monitoring and had the capability of monitoring other ions of interest. This is also an approved EPA nitrate method.

Plant Performance

Salt Dosage Brine Use Factor and Nitrate Leakage

If a Type I or II strong-base anion resin is used, the amount of salt required for regenerating a nitrate-spent bed can be easily estimated from the chemical analysis of water from Well 2 obtained in January 1984. This estimate resulted in the use of 1.5 BV of 6% salt as regenerant to treat 165,900 gal for each service cycle or 260 BV (N). This gives an approximate nitrate leakage of 6.3 mg/L NO_3-N. Salt dosages were initially higher than the target value of 1.5 BV of 6% brine because of the inability of the brine system to deliver a consistent brine dosage. Consistent brine dosages were obtained later by reprogramming to terminate the batch on flow instead of time. Table 3 compares the actual chemical data obtained over the 6-month period with those estimated for a plant using a 260-BV service period.

Nitrate leakages obtained by the plant are in good agreement with the predicted values. Also, any failure to obtain proper declassification will give an erroneous nitrate analysis. The nitrate leakages in Table 3 are from grab samples for certified lab analyses and are subject to variations of sampling and analytical errors.

The plant Brine Use Factor (BUF) values (Table 4) are the average monthly values. This data show that the plant is about 3% less efficient than predicted. This result is quite remarkable considering the assumptions inherent in the method used for making these predictions.

Dilute Brine Quantity

The quantities of both saturated and diluted brine are given in Table 5 together with other quantities used for each of the 6 months.

The amount of saturated brine is noted to be approximately 0.09% of the total water produced, or 0.12% of the amount treated. The corresponding percentages for diluted brine are 0.49% and 0.65%, respectively.

Rinse, Water Backwash, and Total Wastewater

The amounts of water used for rinsi backwash, and total wastewater are list in Table 5.

The plant automatically monitors cc ductivity of rinse water. About 30% exce rinse water is used because conductar falls to a constant value at about 20 gal. Rinse water was not reduced duri this period to allow excess rinsing.

The total wastewater over the 6-mor period is 3.39% of the blended water a 4.52% of the treated water.

Total water recovery is 96.7% over t 6-month period.

This high water recovery, which is even subject to improvement, is one of the main advantages of the ion exchange process over the reverse osmosis process for nitrate removal.

Power Consumption

Daily records of power consumption at the plant have been maintained to obtain electrical power costs for well operation and well plus nitrate plant operation. The

Table 3. *Summary Comparison of Actual Chemical With Predicted Data*

	Plant Data			Estimated*		
Date	Nitrate++ Leakage	Salt lb/ft³	BUF+	Nitrate++ Leakage	Salt lb/ft³	BUF
6-84	2.9	5.94	8.3	4.0	5.94	9.8
7-84	3.2	6.36	9.2	3.4	6.36	9.4
8-84	2.3	6.46	11.8	2.7	6.46	10.8
9-84	0.7	6.48	11.4	2.5	6.48	10.9
10-84	2.9	6.35	11.3	2.4	6.35	10.0
11-84	3.8	6.55	9.7	3.3	6.55	8.8
Averages	2.6	6.35	10.3	2.8	6.36	10.0

*For 260 BV service.

$$+\text{Brine Use Factor} = \frac{\text{Equivalents of Chloride in Fresh Regenerant}}{\text{Equivalents of Nitrate Removed from Influent Water}}$$

++Concentration of nitrate listed as mg NO_3-N/L.
To convert to mg NO_3/L multiply by 4.43

Table 4. *Estimates of BUF for Full Bed Use and Partial Bed Use*

	BUF		Salt Dose (lb/ft³)		% Brine Savings Potential for
Date	260 BV	100% Use	260 BV	100% Use	100% Bed Use
6-84	9.8	8.9	5.94	5.94	9.2
7-84	9.4	8.1	6.36	6.36	13.8
8-84	10.8	8.9	6.46	6.46	17.4
9-84	10.9	8.5	6.48	6.48	22.0
10-84	10.0	7.3	6.35	6.35	27.0
11-84	8.8	7.4	6.55	6.55	15.9
Average					17.6

Table 5. *Secondary Plant Performance Factors*

Date	*Thousands of Gallons Product Water*		*Water Used, Gal*				
	Blend	*Treated*	*Sat. Brine*	*Dilute Brine*	*Rinse Water*	*Backwash*	*Total Waste*
6-84	*5307*	*3516*	*4044*	*37670*	*80990*	*52422*	*171082*
7-84	*3595*	*2673*	*3291*	*29270*	*68640*	*44780*	*142690*
8-84	*3002*	*2617*	*3272*	*7710*	*62340*	*47640*	*117690*
9-84	*4245*	*3433*	*4307*	*22300*	*77340*	*57350*	*156990*
10-84	*4738*	*3055*	*3752*	*16620*	*67360*	*46130*	*130110*
11-84	*3771*	*3163*	*4012*	*7190*	*77060*	*31440*	*115690*
Totals	*24598*	*18457*	*22678*	*120760*	*433730*	*279762*	*834252*
% of Blend	*100*	*75.0*	*0.09*	*0.49*	*1.76*	*1.14*	*3.39*
% of Treated	*133*	*100*	*0.12*	*0.65*	*2.35*	*1.52*	*4.52*

pressure drop through the ion exchange system is approximately 10 psi. Power readings were taken with the well pumping directly into the system and were compared with readings taken while the plant was in operation. Of the total power consumed at the site, 10% was required for the operation of the plant, yielding 0.244 kWh per 1000 gal as the power requirement for plant operation. Power for the brine pump and air compressor are considered negligible.

The cost of this power obtained from the billing of Pacific Gas and Electric Co. is $0.08183 per kWh, making power cost for plant operation $0.019967 per 1000 gal, or $19.97 per million gal of blended water delivered to the system.

Cost Analyses

Capital costs for the McFarland plant are summarized in Table 6. Costs are given for two different vessel heights. The 6-ft height accommodates the 3-ft bed depth and the 10-ft height accommodates a 5-ft bed depth. The cost of the extra side height is the most economical way of increasing bed capacity. O&M costs (Table 7) reflect actual salt and power costs for the 6-month period. The costs presented for normal plant maintenance, miscellaneous costs, and resin replacement may be changed if firm data on resin loss can be obtained. No loss of resin capacity has been detected from the operating data obtained thus far. The 1-hr per day operator cost is still believed to be adequate, since this is mainly a record keeping and inspection effort.

Table 8 summarizes the total treatment costs. The amortized annual capital cost per 1000 gal is based on 100% use of the 1-mgd capacity. The McFarland plant was only operated at 13.7% of its full capacity during this initial period (see Table 9). In this case the amortized annual capital cost per 1000 gal is 7.30 times that shown in Table 8 or $.832 per 1000 gal. As annual plant production falls from 100% to 0% of full capacity use, this cost rises from $0.114 to infinity. O&M cost per 1000 gal are estimated to remain approximately as given in Table 7 regardless of plant usage. The high cost of capital amortization of a partially used plant must be taken into consideration when assessing the cost impact on the consumer. The true water cost that the consumer must pay for operating the plant at less than full capacity can be estimated by comparing consumer costs with and without the plant.

True consumer costs for this report reflect the fact that the consumer receives water from the plant as well as from other wells in the system. In this case the capital cost associated with water supply capital costs in McFarland is the capital cost of wells, the distribution system, and related facilities and improvements (not including a nitrate plant), CS, plus the capital costs shown in Table 8, CP. The total consumer cost of amortizing the capital costs (per 1000 gal of water consumed) by producing a fraction of 1 mgd from existing facilities and the remainder from the nitrate plant is:

Total capital cost/1000 gal = (CS + CP)/1000 gal.

where: CS = cost of wells, distribution system, related facilities, improvements.

CP = capital costs for nitrate plant.

The additional annual amortized capital cost that the consumer must pay for partial (or full) use of the nitrate plant is the amortized capital cost, $41,773, for the nitrate system as shown in Table 8.

The added cost due to O&M of the nitrate plant during this report period is 0.137 times the O&M cost of Table 7.

The total added consumer cost during this report period due to nitrate treatment of 13.7% of the water supplied to the system is:

$/1000 gal = $0.114 + 0.137 x $0.131

or $0.162

These cost analyses will be presented in more detail when all costs over a 2-year period of operation are available and will be discussed in Volume II of this report.

Conclusions and Recommendations

1. The plant was automatically operated for a 6-month period and exhibited the following performance characteristics averaged over the operating period:
   a. Nitrate leakages averaged 5.2 mg/L NO_3-N (23.2 mg/L NO_3) in a blend of treated and untreated water.
   b. The blend consisted of 76.1% treated water and 23.9% untreated water.
   c. Brine dosages were 6.36 lb of salt per ft^3 of resin, or 2.49 per 1000 gal of blended water.
   d. Brine efficiencies averaged 10.3 equivalents of chloride per equivalent of nitrate removed and varied from a low of 8.3 to a high of 11.8.
   e. Water recovery was 96.7% of the water pumped. The remaining 3.3% was discarded as waste brine and wastewater.
   f. Wastewater per 1000 gal of blended watr consisted of 0.92 gal of saturated brine (4.9 gal of dilute brine), 17.6 gal of rinse water, and 11.4 gal of backwash water.
2. Maximum automation was used successfully to satisfy the minimal manpower requirements of a small water system operator. The plant was designed and is being demonstrated primarily with the needs of small communities in mind where wells and distribution systems are already in place. The plant operates at a well site rather than as a central treatment plant.
3. Raw water composition varied during this period of operation. Nitrates varied from 16.0 to 11.1 mg/L NO_3-N. This provided the opportunity to measure the effect of changing water composition on plant performance.
4. Resin beds were operated at 76% capacity during this initial adjustment period to prevent overruns that could occur because of operation problems.

Table 6. Capital Costs for McFarland in 1983

Item	Vessel Size 6'D x 6'H	6'D x 10'H*
I.X. Vessels (3 included)	$ 96,511	$111,741
Onsite construction	81,151	81,154
Brine tank	18,700	18,700
Other	40,045	40,045
Resin 225 ft³ (3 ft depth)	35,000	
424 ft³ (5 ft depth)		56,610
Sub total	$271,407	$309,250
Engineering & administration 15%	40,711	46,388
Total	$311,118	$355,638

*McFarland plant.

Table 7. Operation and Maintenance Costs

Item	Annual Cost	$/1000 gal
Operation (1 hr/day)	$ 4,745	$ 0.013
Normal O&M, .02X(355,638)	7,113	0.019
Power, boost pump (.093/kWh)*	7,289	0.020
Resin replacement (5 yrs)	11,522	0.032
Salt ($31.50/ton), (70% treated in blend)+	14,314	0.034
Miscellaneous	3,000	0.008
Total O&M	$ 47,983	$ 0.131

*244 million gal based on .08183¢ per kWh.
+2490 lb/million gal.

Table 8. Total Capital and O&M Costs

Item	Annual Cost	$/1000 gal
Capital costs - $355,638 (20 years @ 10%)	$41,773	$0.114
Operation & maintenance	47,983	0.131
Total	$89,756	$0.245

5. The effect of operating at less than 100% of the bed capacity is estimated to be a decrease of brine efficiency of approximately 18%.
6. Brine efficiency, nitrate leakage, and bed volumes to nitrate breakthrough can be accurately predicted from ion exchange theory. Computer-based programs being developed can simulate effluent histories and are comparable to those obtained from the plant. They also give chromatographic distributions of ions within spent beds.
7. A 3-ft resin bed depth was used during this period of operation. A 5-ft bed will be used in future tests to obtain comparative data.
8. The power consumed by the plant is 244 kWh per million gal of blended water. This amount is 10% of the total power required for pumping at the well site.
9. Capital costs were $311,118 for a plant with the 3-ft-deep resin bed and $355,683 for a plant with a 5-ft bed. The total costs are $0.245 per 1000 gal of blended water for the 5-ft bed plant (1983 costs). During this report period the plant was operated at only 13.7% capacity. The overall cost to the McFarland community for nitrate removal during this period was $0.162 per 1000 gal of water consumed.
10. The plant is totally automatic in operation with automatic nitrate analysis for monitoring and automatic shut down if nitrate exceeds the MCL in the product water. Computer printouts of operating data are obtained on a daily basis and if alarms occur.
11. Operator tasks are reduced to approximately 1 hr per day and include routine inspection, maintenance, and recordkeeping.
12. Nitrate removal is economically and technically feasible by the ion exchange process. The most undesirable feature is the production and disposal of waste brine. At McFarland during this report period, approximately 1300 lb of waste salts were disposed of in the plant wastewater daily by discharging to the municipal wastewater system. If the plant were operated 24 hr per day, the daily salt discharge would be 2500 lb in 33,000 gal of wastewater. Close monitoring of soil and plant conditions at the disposal site is being conducted.
13. Although nitrate removal by the ion exchange process is largely being considered as a process adaptable for small communities, it is the latter who will find the waste disposal problems the most difficult to solve. Improvements in the process are still required to reduce quantities of waste salts. These can probably be accomplished by use of highly selective nitrate resins, brine recirculation, recovery and separation of sodium nitrate and sodium chloride, and close adjustment of plant operation to changes in raw water composition.
14. Plant shut downs were due to malfunctions of electrical and mechanical equipment and leaks in plastic pipe. All repairs were handled by water company personnel.
15. The adjustment and operation of the plant was complex because the same microprocessor was used for plant control and data collection and reporting. Considerable operating time was lost as a result of writing and testing the data collection portion of the program. The controller required programming by ladder logic, which is cumbersome as a computer language. A separate computer is recommended for data collection at a similar installation.
16. Ion chromatography is satisfactory for routine anion analysis and research, but it definitely requires improvement for continuous on-stream plant monitoring. Additional research on automatic nitrate analysis is recommended.
17. Further development of the nitrate selective resin is recommended because use of a nitrate selective resin would eliminate the possibility of nitrate dumping and would reduce introduction of chloride into product water.
18. Further research on waste brine disposal and brine reuse is recom-

mended to eliminate the buildup of waste nitrate and other salts in the disposal area and underlying ground water.

The full report was submitted in fulfillment of Cooperative Agreement No. CR808902-02-0 by McFarland Mutual Water Company under the sponsorship of the U.S. Environmental Protection Agency.

Table 9. *Summary of Monthly Data*

Date	Salt Dose* lb/ft³	Salt Dose* lb/1000 gal of Blend	% Treated* in Blend	Nitrate-N (mg/L)* in Blend	1000 gal Delivered
6-84	5.94	2.01	66.2	4.8	5,307
7-84	6.36	2.42	74.0	5.0	3,595
8-84	6.46	2.89	87.2	5.6	3,002
9-84	6.48	2.69	80.9	5.3	4,245
10-84	6.35	2.10	64.5	5.4	4,738
11-84	6.55	2.82	83.8	5.2	3,771
Averages	6.36	2.49	76.1	5.2	

*Monthly averages.

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***Richard Lauch** is the EPA Project Officer (see below).*
The complete report, entitled "Nitrate Removal from Contaminated Water Supplies: Volume I. Design and Initial Performance of a Nitrate Removal Plant," (Order No. PB 87-145 470/AS; Cost: $18.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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Research and Development

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EPA

Project Summary

Nitrate Removal from Contaminated Water Supplies: Volume II

Gerald A. Guter

Nitrate removal from contaminated water using the ion exchange process was evaluated at a 1 million gal a day (mgd) plant at McFarland, CA. The plant supplied most of the community's water needs during 1985 and 1986. This document summarizes the second of a two-volume report and focuses on analysis of operation and maintenance (O&M) costs and plant performance from December 1, 1984, to January 1, 1987. Volume I focused on the design and the first 6 months of its automatic operation.

Accurate cost and operational data were obtained to determine actual treatment costs. When the plant started operation, nitrate levels in the raw water were 15.8 mg NO3-N/L. As operation continued over the 3 yr, nitrate levels fell, as well as the amount of other anions. A correlation was observed between long-term monthly pumping rate and nitrate level in the raw water.

It is believed that this data comprises the most comprehensive cost and performance information ever accumulated on an ion exchange nitrate removal system for the production of safe drinking water from contaminated groundwater. Extensive data on disposal of waste from the plant is also included.

Actual O&M costs of 8.5¢/1000 gal (based on design capacity of 1 mgd) were 36% lower than cost estimates published previously. These lower costs are attributable to a number of factors that include: drop in nitrate and sulfate levels in the raw water, automatic operation, automatic hourly nitrate measurement, automatic recording of plant operating conditions, daily remote telecomputer communication, operation based on partial regeneration, and a column design which provided nearly 100% column efficiency.

Wastewater composition and production were studied to characterize the type of wastewater produced. The wastewater entered the local sewer collection system and eventually was disposed of as irrigation water for cotton production. Soil and water conditions were monitored over a 4 yr period at the disposal area. Only slight effects were noted in soil characteristics and groundwater composition from nearby wells. Approximately 125 tons of waste solids are disposed of per year at the site and a serious impact is expected to occur on a long-term basis. This is of special concern because of a second plant to be operational in McFarland in 1987.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The McFarland, CA, nitrate removal demonstration project involved the design, construction, and operation of a nitrate removal plant at Well No. 2 owned and operated by the McFarland Mutual Water Company. This volume covers the nitrate plant operation from December 1, 1984, to January 1, 1987. Volume 1 covered the design, startup, and initial performance of the plant (Reference 1). The period of operation spanned by these two volumes is the 38 months from November of 1983 to January of 1987. During most of this time the plant functioned as the community's primary water supply.

The plant continues to serve the community as a major source of drinking water that meets the nitrate maximum contaminant level (MCL). A second plant is presently under construction at Well No. 4 and is anticipated to be operational in the summer of 1987. The full report includes cost information on the second McFarland nitrate plant. A third project is being planned to treat other wells with the existing plants.

Experimental work was also done under this program on nitrate selective resins, wastewater recycling, automatic nitrate monitoring, and telecomputer monitoring.

The grant period covered by both volumes of this report is from September 1981 to April 1987. The work effort is a followup to work done under a previous grant reported in Reference 2.

Much information on plant design and related research has been published. In addition to the above two references, previously published papers contain information developed under both grants (References 3, 4, 5, 6, and 7). A U.S. Patent was issued October 1984 on the use of a nitrate selective resin in water treatment (Reference 8).

Plant Operation

The data period covered in this report begins December 1, 1984, immediately after the period covered in Volume I and continues to January 1, 1987. Data for the months preceding December 1984 are also listed in some of the following data tables for comparison. Data for the period up to January 1, 1986, are given detailed analyses, and are believed to adequately represent the treatment costs. Data for 1986 are listed in summary form and are important because of the use of the 5-ft resin bed instead of the 3-ft bed used earlier.

Daily records of flows, flow rates, and nitrate levels were maintained throughout the above period of operation. Data were obtained by manual readings, record keeping, and automatic data logging by the microprocessor. The plant was operated entirely in the automatic mode. The most time consuming tasks of the operator were the data logging and record keeping of operation.

From the daily reports described above, monthly reports were compiled in conformance with the requirements of the California State Division of Health. Table 1 is an example of data for 1 month of operation.

In the table, column 2 gives the daily quantity of water pumped to the distribution system. This, water was a blend of the treated water and bypassed quantities shown in columns 3 and 4. Column 5 lists the amounts of saturated brine used daily for regeneration. The next two columns list the average nitrate levels in the blended water delivered to the distribution system. The remainder of the columns lists the type of wastewater produced and the daily totals. The last line of each of the columns gives the total water quantity and monthly average nitrate level.

Table 2 lists the anion compositions of raw water, treated water, and blended water. These data are taken from monthly analyses performed by a State certified laboratory.

It can be noted that the raw water quality gradually improved and nitrate values dropped below the MCL in June 1985. Decreases in the other interfering anions also occurred over this period of operation. Continuation of operation was required by the State of California to maintain nitrate below 7.9 mg NO3-N/L.

Table 3 shows brine dosages and service batch with monthly summaries of other data. Salt dose was maintained at 5.61 lb/ft^3 of resin [1.5 bed volume (BV) of 6% NaCl solution] although actually measured amounts varied, but averaged 5.42. The percent of treated water in the distributed blend was manually adjusted from time to time to reflect actual or anticipated seasonal changes in untreated water composition and to maintain the nitrate level below 7.9 mg NO3-N/L as required by the State operating permit.

Primary performance data are evaluated by comparing the actual performance data with estimates from ion exchange theory. The major parameters related to operating costs here are nitrate leakages and the consumption of regenerant salt per amount of nitrate removed from raw water.

Five criteria can be used to evaluate plant performance. These are: salt dosage requirements, brine use factors, nitrate leakages, column efficiency, and effluent histories. These quantities were measured and compared to projected values or estimates from theoretical considerations to determine if the plant performance was optimum, or if not, to determine the cause of inefficiency.

The secondary plant performance factors for the 1985 year are given in Table 4. The overall percentages of brine and produced wastewater are compared in the last two lines of the table. The wastewater disposed to the sewer system was only 2.53% of the water pumped, giving a remarkably high water recovery of 97.47%. Improved secondary performance was achieved in 1986.

Other operating data of interest are given in Table 5, which shows the average monthly brine dose for the regeneration of each vessel. The number of regenerations varied from about one to three per day. The amount of sodium chloride used for regeneration varied from about 11,000 lb to 53,000 lb per month. The amount delivered per truck load to the site was 25,000 lb. The peak month required about two deliveries per month and the low month required one delivery about every 2 months. The last column gives the service volume settings per month. These settings were increased during the last 2 months to accommodate the improvement in water quality and the anticipated changes for testing the 5-ft resin bed operation.

Capital and O&M Costs

Capital Costs

The capital costs for the construction of the nitrate plant at Well No. 2 are given in Table 6. Table 6 shows costs for two different sizes of vessels and resin beds to accommodate 3-ft-deep beds and 5-ft beds. The first McFarland plant was constructed with taller vessels to accommodate both beds. The cost was $355,638 (1983).

O&M Costs

In Volume 1 (Reference 1) and previous publications (References 2, 5, and 6), O&M costs were based on a mix of actual and estimated cost data. These costs have been revised using figures from McFarland Mutual Water Company files for the years 1985 and 1986. The cost data are listed in Table 7.

Total Costs

Two methods that are very useful for analyzing costs are presented here. The two methods are total costs based on design flow and total costs based on actual plant flow. The full report discusses a number of other ways to analyze costs including costs that are specific to the McFarland, CA, community.

Based on design flow of 1 mgd, Table 8 shows O&M costs of 8.5¢/1000 gal (1984-1985) and capital costs of 9.9¢/1000 gal (1983). Capital costs were amortized over 20 yr at 8% interest. Therefore, total cost including capital plus O&M was 18.4¢/1000 gal. Construction cost increased approximately 1%/yr over the 1983-1986 period and therefore total cost should be adjusted upward slightly to reflect this.

Based on actual flow, the plant processed 343 million gal of water over the 1985-1986 period for an average of 0.47 mgd. Fixed O&M costs (Table 8) will increase from 4.1¢/1000 gal to 8.7¢/1000 gal and total O&M cost will be 13.1¢/1000 gal. Capital cost will increase from 9.9¢/1000 gal to 21.1¢/1000 gal. Therefore, total costs, when pumping at an average rate of 0.47 mgd was 34.2¢/1000 gal.

Excellent information on cost estimates for small water systems is also given in Reference 9.

Conclusions and Recommendations

1. The nitrate plant at Well No. 2 in McFarland, CA, was successfully operated during 1985 and 1986 to provide the community with 343 million gal (over the 2 yr) of drinking water meeting the nitrate standard. This amount of water met 57% of the total demand for the community. On a yearly basis, the plant produced 197.4 million gal (65.8% of the water) in 1985 and 145.58 million gal (48.5% of the water) in 1986.
2. The capital cost for the McFarland plant was $355,638 (1983). Total annual cost for capital amortized over 20 yr at 8% interest was $36,232. The average annual O&M cost over the 2-yr (1985-1986) period was $30,712. Based on design capacity of 1 mgd, capital cost was 9.9¢/1000 gal and O&M cost was 8.5¢/1000 gal for a total cost of 18.4¢/1000 gal. The O&M cost was 36% lower than previously projected and total costs were 25% lower than previously projected.

Table 1. *Plant Records August 1985*

	Gallons of Water				*Average Nitrate mg/L in Blended Water*		*Gallons of Wastewater*			
Date	*To System*	*Treated by IX*	*By-passed*	*Gallons Saturated Brine*	*As NO3*	*As N*	*Dilute Brine*	*Slow Rinse*	*Backwash*	*Total Gallons Wastewater*
1	854,000	608,200	245,800	718	27.0	6.11	1,440	11,560	7,990	20,990
2	907,300	636,600	270,700	658	25.6	5.80	1,460	14,173	10,646	26,279
3	907,300	636,600	270,700	658	--	--	1,460	14,173	10,646	26,279
4	907,300	636,600	270,700	658	--	--	1,460	14,173	10,646	26,279
5	867,000	604,700	262,300	719	28.0	6.34	1,540	14,420	10,480	26,440
6	933,000	640,400	292,600	718	27.6	6.25	1,540	12,310	8,000	21,850
7	900,000	636,800	263,200	547	29.0	6.57	1,160	12,930	10,830	24,920
8	957,000	657,200	299,800	711	31.0	7.02	1,470	14,420	10,670	26,560
9	879,700	605,200	274,500	697	30.0	6.79	1,590	14,286	9,727	25,603
10	879,700	605,200	274,500	697	--	--	1,590	14,286	9,727	25,603
11	879,700	605,200	274,500	697	--	--	1,590	14,286	9,727	25,603
12	905,000	627,100	277,900	855	29.0	6.57	6,930	18,030	13,310	38,270
13	902,000	618,900	283,100	719	27.0	6.11	1,390	14,420	10,610	26,420
14	925,000	649,100	275,900	718	29.0	6.57	1,620	14,420	9,960	26,000
15	953,000	708,300	244,700	665	28.4	6.43	1,640	14,420	11,470	27,530
16	926,000	829,600	96,400	539	29.4	6.66	1,250	10,820	8,110	20,180
17	906,000	623,300	282,700	719	30.4	6.88	1,120	11,920	10,465	23,505
18	906,000	623,300	282,700	719	--	--	1,120	11,920	10,465	23,505
19	912,000	626,800	285,200	719	27.4	6.20	1,670	19,420	10,520	31,610
20	948,000	650,700	297,300	718	25.6	5.80	1,650	12,790	7,190	21,630
21	955,000	650,600	304,400	712	27.4	6.20	1,610	13,830	10,520	25,960
22	274,000	189,000	85,000	180	31.0	7.02	340	5,830	5,380	11,550
23	931,300	434,200	497,100	760	29.8	6.75	1,696	13,526	9,743	24,965
24	931,300	434,200	497,100	760	--	--	1,696	13,526	9,743	24,965
25	931,300	434,200	497,100	760	--	--	1,696	13,526	9,743	24,965
26	1,250,100	1,250,100	--	539	29.0	6.57	1,240	14,170	10,210	25,620
27	473,500	322,400	151,100	359	26.6	6.02	825	7,215	5,240	13,280
28	473,500	322,400	151,100	359	--	--	825	7,215	5,240	13,280
29	921,500	621,700	299,800	643	28.4	6.43	1,490	12,620	9,080	23,190
30	921,500	621,700	299,800	643	--	--	1,490	12,620	9,080	23,190
31	954,500	627,100	327,400	705	30.2	6.84	1,680	14,420	12,960	29,060
Total	27,172,500	18,737,400	8,435,100	20,269	*28.5	*6.45	49,278	407,675	298,128	755,081

*Average value

Table 2. *Monthly Anion Analyses by Certified Lab (Mg/L)*

	Nitrate*			Sulfate**			Bicarbonate			Chloride		
Month	Raw	Treated	Blend	Raw	Treated	Blend	Raw	Treated	Blend	Raw	Treated	Blend
1-84	71	25	40	115	0	34	104	100	102	88	203	169
4-84	66	21	37	95	0	38	113	21	38	84	208	161
5-84	60	20	28	100	0	16	100	38	80	77	22	177
6-84	56	13	26	95	0	27	87	75	50	75	177	158
7-84	58	14	24	85	0	21	70	57	67	74	174	148
8-84	50	10	14	80	0	0	69	61	55	68	155	154
9-84	49	3	20	76	0	17	75	43	49	58	148	128
10-84	51	13	31	60	0	36	80	21	50	60	166	122
11-84	62	17	28	80	0	28	82	47	54	62	159	112
12-84	50	15	27	75	0	26	78	70	45	59	139	117
1-85	58	18	37	90	0	42	88	85	63	90	155	121
2-85	52	16	28	82	0	29	78	12	57	57	172	115
3-85	44	12	28	70	0	32	76	48	65	55	144	119
4-85	52	14	22	80	0	17	81	90	64	61	135	127
5-85	49	13	15	68	0	0	75	22	17	60	159	165
6-85	43	12	21	68	0	21	67	13	46	53	153	109
7-85	41	12	20	55	0	20	66	17	44	50	137	102
8-85	41	11	--	60	0	--	63	10	--	49	140	--
9-85	40	11	19	60	0	22	60	21	36	47	131	94
10-85	40	11	21	73	0	19	77	23	47	63	125	94
11-85	40	17	--	--	0	--	--	--	--	--	92	--
12-85	33	9	28	50	0	31	67	62	65	46	100	67

*Concentration of nitrates are given as mg NO3/L.
To convert to mg NO3-N/L, divide values in above table by 4.43.

**0 = less than 5.00.

Table 3. *Summary of Operating Data to January 1, 1986 Data*

	Salt Dose*			mg/L in Blend*			
Month	lb/ft^3 of Resin	lb/1000 gal of Blend	% Treated* in Blend	as NO3	as N	1000 gal Delivered	Cumulative Million gal Delivered
6-84	5.94	2.01	66.20	21.20	4.79	5,307	5.31
7-84	6.36	2.42	74.00	22.30	5.04	3,595	8.91
8-84	6.46	2.89	87.20	24.70	5.58	3,002	11.91
9-84	6.48	2.69	80.90	23.40	5.29	4,245	16.15
10-84	6.35	2.10	64.50	23.80	5.38	4,738	20.89
11-84	6.55	2.82	83.80	23.20	5.24	3,771	24.66
Average	6.36	2.49	76.10	23.20	5.24	4,110	
12-84	5.60	1.78	61.70	24.30	5.49	12,402	41.17
1-85	5.08	1.74	66.50	26.60	6.01	7,826	49.00
2-85	4.85	1.85	74.20	28.10	6.35	16,845	65.84
3-85	4.90	1.68	66.70	25.70	5.81	6,615	72.46
4-85	5.65	1.95	67.00	21.40	4.83	5,837	78.30
5-85	5.41	2.24	80.70	26.70	6.03	6,070	84.37
6-85	5.78	2.21	74.30	24.80	5.60	19,462	103.83
7-85	5.66	2.04	70.10	26.10	5.90	21,481	125.25
8-85	5.57	1.97	69.00	28.50	6.44	27,173	152.42
9-85	5.91	1.99	65.40	25.20	5.69	24,736	177.16
10-85	5.50	1.91	67.40	25.30	5.71	20,067	197.22
11-85	4.97	1.71	81.00	25.50	5.76	19,007	216.23
12-85	5.53	1.48	78.70	25.40	5.74	22,356	238.59
Average	5.42	1.89	70.98	25.66	5.80	16,139	

Service Batch Per Vessel (gal)		BV
Prior to 11/6/85	1659.00x 100	260.93
11/6/85	2000.00	314.56
12/12/85	2500.00x 100	393.21

1/1/86 5-ft beds installed

*Averages per given month

Table 4. *Secondary Plant Performance Factors*

Date	Produced Water (1000 gal) Blend	Produced Water (1000 gal) Treated	Brine (gal) Saturated	Brine (gal) Dilute	Wastewater (100 gal) Rinse	Wastewater (100 gal) Backwash	Wastewater (100 gal) Total
12-84	12,402	7,647	8,322	13,220	1,658	725	2,516
1-85	7,826	5,201	5,132	13,722	874	573	1,584
2-85	16,845	12,492	11,781	30,576	2,359	1,372	4,036
3-85	6,615	4,415	4,205	15,430	807	521	1,483
4-85	5,837	3,910	4,295	8,180	841	563	1,487
5-85	6,070	4,900	5,148	15,154	1,036	875	2,064
6-85	19,462	14,467	16,238	41,441	3,295	2,536	6,246
7-85	21,418	15,009	16,500	37,646	3,376	2,424	6,178
8-85	27,173	18,737	20,269	49,278	4,076	2,981	7,550
9-85	24,736	16,168	18,553	81,917	3,773	2,655	7,248
10-85	20,067	13,527	14,448	33,585	2,991	1,980	5,308
11-85	19,007	15,392	12,295	37,078	2,572	1,649	4,592
12-85	22,356	17,593	12,500	45,932	1,406	967	2,833
Monthly Average	16,139	11,497	11,514	32,550	2,236	1,525	4,087
% of Blend	100.00	71.24	.07	.20	1.39	.95	2.53
% of Treated	140.38	100.00	.10	.28	1.95	1.33	3.55

Table 5. *Other Plant Operating Data*

Date	Average Brine Dose Per Regeneration (gal)*	Number of Regenerations During Month	Pounds of Sodium Chloride Per Month	Average Setting of Service Volume Per Month (BV)**
12-84	179.90	46.26	22,028	260
1-85	163.10	31.46	13,584	260
2-85	155.89	75.57	31,184	260
3-85	157.43	26.71	11,130	260
4-85	181.54	23.66	11,368	260
5-85	173.64	29.65	13,626	260
6-85	185.54	87.52	42,981	260
7-85	181.72	90.80	43,675	260
8-85	178.82	113.35	53,652	260
9-85	189.68	97.81	49,109	260
10-85	176.56	81.83	38,243	260
11-85	183.85	66.88	32,544	306
12-85	180.69	69.18	33,087	365

*For 85 ft^3 resin bed
**One BV = 635.8 gal

3. The plant actually processed 343 million gal of water over the 1985-1986 period for an average of 0.47 mgd. Based on the actual flow of 0.47 mgd, 47% of design capacity, capital cost was 21.1¢/1000 gal (amortized over 20 yr at 8% interest) and O&M cost was 13.1¢/1000 gal for a total of 34.2¢/1000 gal.

4. Over the 2-yr period of operation, 98.2% of the water pumped from the well was distributed to the system after nitrate reduction to approximately 6.8 mg NO3-N/L. The 1.8% not distributed was discharged as wastewater.

5. The amount of wastewater produced per 1000 gal of distributed water consisted of 1.4 gal of brine, 6.6 gal of rinse water, and 10.3 gal of backwash water.

6. The plant was operated with a 3-ft-deep bed in 1985 and a 5-ft bed in 1986. No differences in performance were observed which could be attributed to the two different depths.

Table 6. Capital Costs, McFarland Well No. 2 Plant (1983)

Item	Vessel Size 6'D x 6'H	6'D x 10'H*
I.X. Vessels (3 included)	$ 96,511	$111,741
On-site Construction	81,151	81,154
Brine Tank	18,700	18,700
Other	40,045	40,045
Resin 255 cu. ft (3 ft depth)	35,000	
424 cu. ft (5 ft depth)		56,610
Sub Total	$271,407	$309,250
Engineering & Administration 15%	40,711	46,388
Total	$311,118	$355,638

*McFarland's Plant

Table 7. Operation and Maintenance Costs

Cost Item	Dollars 1985	1986	Average $ per Million gal Delivered
Air Compressor	523.81		
Hach Kits, Reagents	555.99	103.30	
D.I. Water Service	162.50	245.98	
Piping Supplies	4.20		
Omega, Panel Repair	180.00	284.85	
Meter Repair	692.95		
Dionex Repair	545.15	3,505.00	
AMATEK, Batch Meter Repair	161.35	973.21	
Grainger Compressor Repair	21.60		
Heater Repair		37.50	
Valve Actuator Springs		1,326.00	
Compressor	391.40		
Chemical Analyses	494.50	494.50	
Telephone	120.16	398.82	
Operator (1 hr/day @ $9.40/hr)	3,420.05	3,420.05	
Engineering/Operator Assist	6,000.00	5,547.98	
Sub Total	13,273.66	16,337.19	
Annual Average	14,805.42		
Production Related Costs			
Salt	3,464.20	4,623.80	24.65
Electrical	3,760.00	2,740.00	18.93
Sub Total	7,224.20	7,363.80	43.58

Table 8. Total Costs*

O&M Costs (1984/85)	Annual Costs	$/1000 gal	$/Acre-ft
O&M Fixed Costs	14,805.42	.041	13.35
Electric $18.93/mg	6,909.45	.019	6.19
Salt $24 65/mg	8,997 25	.025	8.15
Sub Total	30,712.12	.085	27.69
Capital Costs (1983)			
$355,638 8% 20 yr	36,221.73	.099	32.26
Total Costs	66,933.85	.184	59.95

*Based on design capacity of 1 MGD.

7. The amount of resin lost and lowering of resin capacity during the 3-yr of operation were too small to be measured. No resin replacement costs are included in the above O&M costs.

8. A significant finding was made which may affect future operation of the two nitrate plants in McFarland. Data show that if the well is continuously pumped, the need for nitrate treatment decreases. Methods of managing well operation are being studied to use this information.

9. The plant continued to operate automatically. Approximately 1-hr of time by a trained operator was required to perform daily routine tasks. The operator was assisted by a remote telecomputer monitoring system to provide expert plant monitoring and assistance in adjusting the plant for optimum operation.

10. Nitrate analyses were performed automatically every hour on a 24-hr day. These data were transmitted to a computer file and to recording charts as permanent records.

11. Experimental work was continued on development of resins with nitrate-to-sulfate selectivity. One resin, a tributyl amine strong base resin, showed unusually high selectivity. A United States patent was issued on use of this resin in nitrate removal as a result of this work.

12. Computer programs to simulate the ion exchange process were widely used during these studies. The programs were useful in the development of nitrate selective resins and in assessing plant performance.

13. The above costs do not include costs of disposing wastes from the plant. The composition of these wastes was determined and laboratory studies on their reuse by recycling were made.

14. During the 1985-1986 period, over 250 tons of salt were consumed in the nitrate removal process. The water containing these waste salts was disposed of to the McFarland sewer collection system where it was blended with raw municipal waste, treated in aeration ponds, and disposed of to 120 acres of irrigated cotton crops.

15. The disposal of this large quantity of waste salt to the environment poses serious questions about the fate of these materials and their impact on the local environment.

16. Increases in TDS of the irrigation water were consistent with expectations. No water quality parameters changed significantly enough to affect the use of the water in cotton irrigation.

17. Soil chemistry changed slightly and showed increased sodium and less calcium. The indices used show that a sodium-calcium equilibrium has been reached and no further changes are expected unless there is an increased rate of brine disposal.

18. There was a significant increase in nitrate content of the soil water over the monitoring period. This impact is being studied by the city of McFarland to see if fertilizer costs can be reduced.

19. Groundwater samples were taken from three different wells adjacent to the disposal area. Although there are indications that waste salts have reached the groundwater table, there was no observable increase in nitrate or TDS levels in the wells. It is expected, however, that ground water deterioration will eventually occur.

20. Disposal of wastewater from a nitrate plant remains a problem which will intensify in McFarland when the second plant becomes operational. Monitoring of the disposal area should continue. Methods of recovery and reuse of wastewater salts need to be developed to reduce the discharge of these materials to a minimum.

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The complete report, entitled "Nitrate Removal from Contaminated Water Supplies, Volume II. Final Report," (Order No. PB 87-194 577/AS; Cost: $18.95, subject to change) will be available only from:

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